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SATELLITE-DERIVED VEGETATION INDICES: A NEW CLIMATIC VARIABLE?

K.P. Gallo
Satellite Research Laboratory, NOAA/NESDIS
EROS Data Center, Sioux Falls, SD 57198

1. INTRODUCTION

Visible (0.58 to 0.68 µm) and near-infrared (0.72 to 1.0 µm) data acquired by the National Oceanic and Atmospheric Administrations' Advanced Very High Resolution Radiometer (AVHRR) have been utilized by numerous researchers to compute vegetation indices. These indices have been used to monitor seasonal fluctuations in the extent of vegetation (Goward et al., 1985 and 1987; Justice et al., 1985; Justice, 1986; Schneider et al., 1985), classify land cover types (Lloyd, 1989; Tucker et al., 1985), monitor monthly variations in globally averaged atmospheric CO_2 (Tucker et al., 1986), and monitor vegetation development and the length of crop growing seasons (Gallo and Flesch, 1989; Malingreau, 1986).

The association between vegetation indices and vegetation development, as well as the length of crop growing seasons, suggests that vegetation indices may be useful as indicators of climatic variability. Malingreau (1986) demonstrated that seasonally integrated values of a vegetation index for northern Thailand were considerably less during the El Nino drought of 1982-1983 compared to non-drought growing seasons. Gallo and Heddinghaus (1989) similarly observed that seasonally integrated values of a vegetation index were much less in the U.S. Corn Belt during a drought (1988) compared to non-drought (1987) growing season. Thermal data from the NOAA-AVHRR (Gutman, 1990), GOES (Tarpley, 1988) and microwave data (Choudhury, 1988; Choudhury et al., 1987) have also been identified for use as potential monitors of vegetation and related climatological variables. Goward (1989) provides an overview of previous and potential uses of several vegetation indices.

Satellite-derived vegetation indices are currently under evaluation for use as indicators of inter-regional, or year-to-year differences in several climatic variables. If relationships between climatic conditions and vegetation indices can be established then vegetation indices might be utilized as one of many tools to monitor global climatic change.

2. DATA ANALYSIS

The availability of near-global (55° S to 75° N) vegetation index data from the NOAA AVHRR, in a mapped format, readily permits temporal analyses for specific geographic regions of the world. Visible and near-infrared data available weekly from the Global Vegetation Index (GVI) product of NOAA/NESDIS (Tarpley et al., 1984; NOAA/NESDIS, 1986; Ohring et al., 1989) were calibrated (Rao, 1987) and used to compute the difference (diff),

$$\text{diff} = \text{near-IR} - \text{visible} \quad ,$$

and normalized difference vegetation indices (ND),

$$\text{ND} = \frac{(\text{near-IR} - \text{visible})}{(\text{near-IR} + \text{visible})} \quad .$$

The spatial resolution of the GVI data utilized was approximately 15 km.

2.1 U.S. Corn Belt Analyses

The vegetation indices were computed for specific Climatic Divisions located in the Corn Belt of the United States during 1987 and 1988. The examined Climatic Divisions included regions primarily devoted to agriculture and rangeland. Climatic Divisions that were primarily composed of urban (NE Illinois) or forested (S Illinois and S Indiana) land surface features were not included in this analysis as urban areas typically display low vegetation index values. Additionally, vegetated land within urban areas, trees or watered lawns, would not likely exhibit climatic influences other than highly abnormal climatic conditions (e.g. drought conditions severe enough that watering of lawns is prohibited and green lawns turn brown). Forested regions were also excluded because the roots of trees are usually deep enough to meet most moisture requirements, even during a drought.

Visible and near-IR data were utilized to exclude pixels of data that included clouds. The mean weekly vegetation index values for each Climatic Division were computed and merged with weekly climatic data products (Motha and Heddinghaus, 1986) from the Climate Analysis Center of NOAA. Seasonally integrated values of the vegetation indices and climatic variables (Table 1) were computed for the June through August portion of the two years included in this study.

Table 1. Climatic variables examined for the Climatic Divisions included in this study (June through August, 1987 and 1988).

Seasonal ET/PET
Seasonal precipitation
Seasonal Crop Moisture Index

The seasonally integrated (June through August) climatic variables were compared to seasonally integrated vegetation indices to determine if the vegetation indices could be utilized as indicators of year-to-year climatic variability.

2.2 Global Analyses

Calibrated weekly GVI data of 1987 were processed to remove cloud contaminated data, data drops due to instrument or data relay problems, and data acquired at solar elevation angles less than 15°. The weekly data were composited biweekly to further reduce cloud contamination. Traditional climatic analyses were applied to the biweekly GVI data. Yearly maximum and minimum ND vegetation index values were computed, as were the range and time of maximum. Additional analyses included the cumulation of ND days; biweekly ND values above a threshold of 0.1 were weighted by the number of days in the sample interval (14) and cumulated over a year. Yearly duration of green vegetation, defined as number of weeks above a ND threshold of 0.1, was also computed.

3. RESULTS AND DISCUSSION

3.1 U.S. Corn Belt Analyses

The difference vegetation index values for the East Climatic Division of Illinois (Climatic Division no. 5) were computed for each week of the 1987 and 1988 growing seasons (Figure 1a). The normal rainfall, from 1 April (calendar date 91) through 31 July (date 212) for this climatic division, is 41.1 cm. Rainfall during this interval in 1987 was 40.1 cm while in 1988 the rainfall was only 14.7 cm. Early in the growing season, up through mid-May (date 137 = 17 May) the difference index of 1988 was similar to that of 1987. The difference index after mid-May, however, increased at a greater rate in 1987 compared to 1988. The difference index in mid-July of 1988 was 40% less than the value in 1987, a year with near-normal precipitation from April through July.

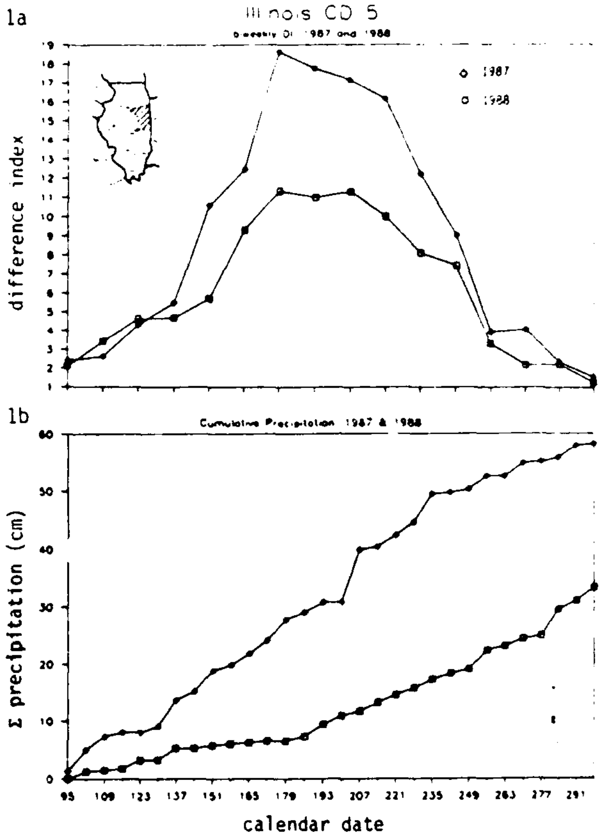

Fig. 1. 1987 and 1988 Analyses: biweekly difference vegetation index values (1a) and cumulated precipitation (1b) of 1987 and 1988 for Illinois CD #5.

Seasonally cumulated climatic variables (June through August) of 1987 and 1988 were linearly associated with the difference index values cumulated over the same interval (Figure 2). Lower seasonal values of the Crop Moisture Index (Palmer, 1968) ET/PET (Thornthwaite, 1948), and precipitation throughout the Corn Belt corresponded to lower seasonal totals of the difference index in 1988 compared to 1987.

The comparison of the difference vegetation index for the crop growing seasons of 1987 and 1988 demonstrates the potential use of these data to monitor vegetation condition, and indirectly, the climatic fluctuations that lead to the displayed differences in the difference indices of the two years.

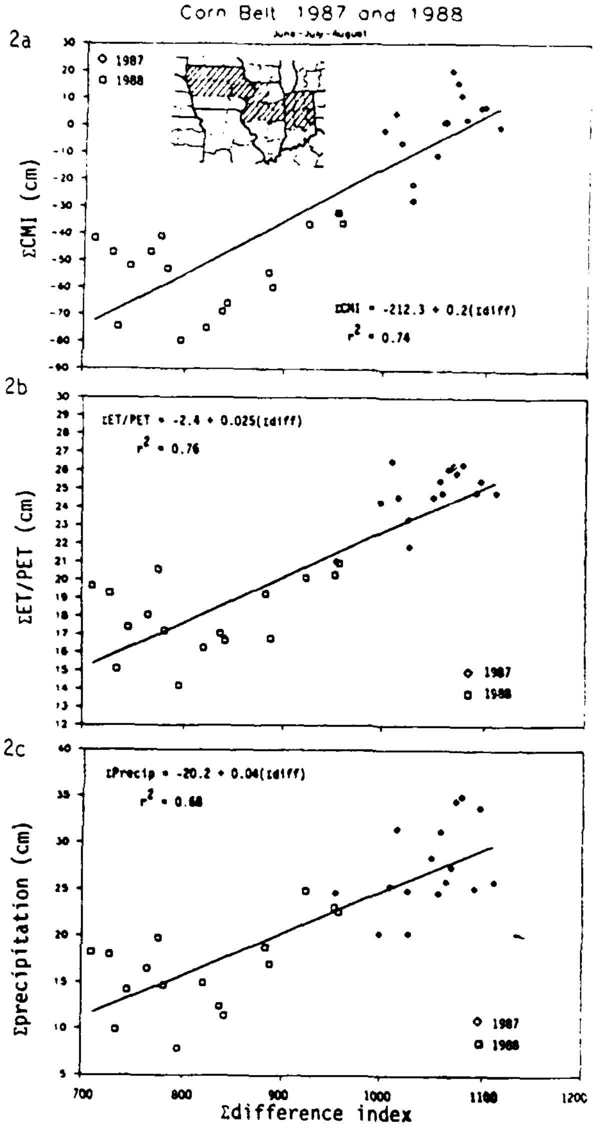

Fig. 2. 1987 and 1988 Analyses (cont.): Seasonally cumulated (June through August) values of; (2a) the Crop Moisture Index (CMI), (2b) ratio of evapotranspiration (ET) to potential ET (PET), and (2c) precipitation, displayed as a function of the seasonally cumulated difference vegetation index for the indicated CD's of the Corn Belt in 1987 and 1988.

3.2 Global Analyses

Yearly bi-weekly ND vegetation index and cumulated ND values for two diverse climatic regions display general trends (Figures 3 and 4) that can be associated with the climate of the regions, without any prior knowledge of the location of the selected data. The relatively constant bi-weekly values of the vegetation index for the location displayed in Figure 3 suggests a relatively mild climate that includes temperatures and precipitation that would support the year-round presence of green vegetation. The location of the extracted data displayed in Figure 3 was within the tropical savanna (Espenshade and Morrison, 1986) region of central Brazil.

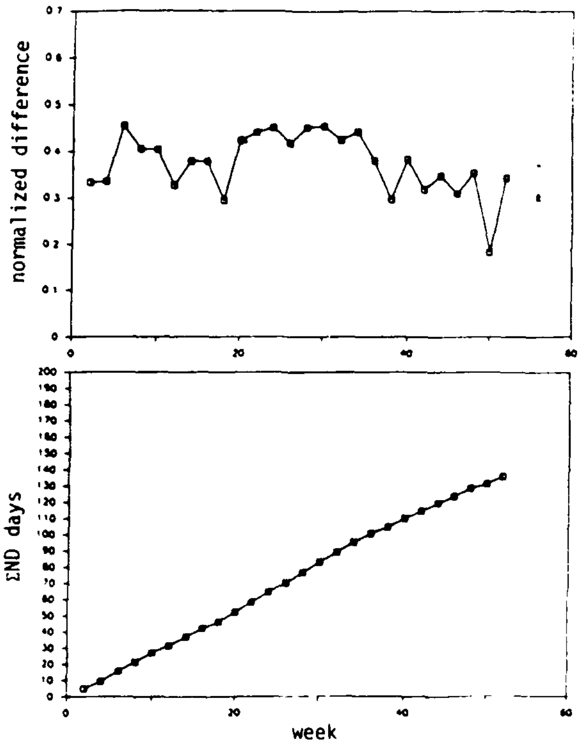

Fig. 3. Global Analyses: biweekly (top) and seasonally cumulated (bottom) values of the ND vegetation index for a site in the tropical savanna region of Brazil.

The yearly maximum, minimum, and range in the ND values of the location displayed in Figure 4 suggest that the yearly climate of this region includes an interval of either dry or cold conditions that would result in the disappearance of green vegetation. The time of the maximum and minimum vegetation index values indicate that the mid-May (week 20) through mid-October (week 41) interval includes mild temperatures and/or adequate precipitation to support the presence of vegetation. The location of the extracted data for Figure 4 was within the continental climate of the central United States.

The results of these initial analyses suggest that vegetation indices may have a potential use as indicators of general climatic conditions and as monitors of year-to-year variability in specific climatic variables (e.g., seasonal precipitation, ET/PET, and Crop Moisture Index). Relationships between vegetation indices and climatic variables will continue to be studied as potential indicators of climatic conditions. If relationships between vegetation indices and climatic conditions can be established then vegetation indices might be ~~utilized~~ as one of many tools to monitor changes in global climatic conditions.

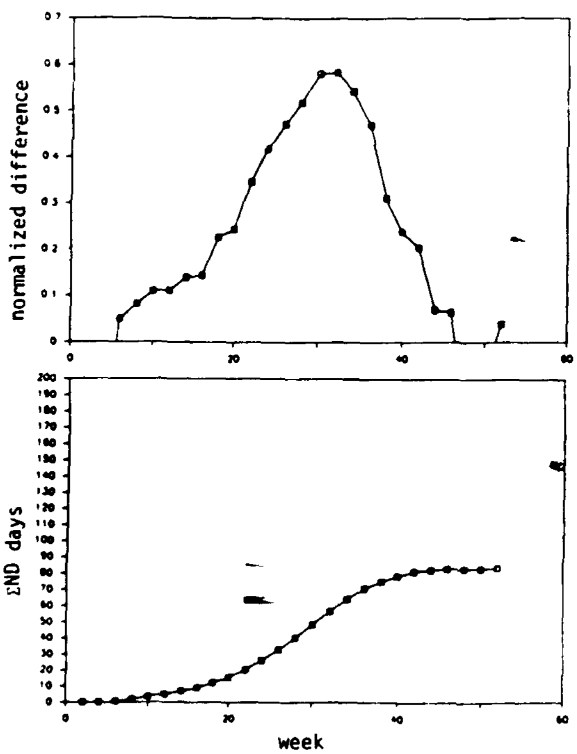

Fig. 4. Global Analyses (cont.): biweekly (top) and seasonally cumulated (bottom) values of the ND vegetation index for a site in the central United States.

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